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Short pulse absorption dynamics in a p-i-n InGaAsP MQW waveguide saturable absorber

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Abstract *The saturation properties and absorption dynamics of an InGaAsP MQW waveguide saturable absorber is measured using short 200-fs and 1-ps pulses. The dependence on the pulse energy and reverse bias is characterized.*

Introduction

Semiconductor saturable absorbers (SA) are successfully used both in pulse sources and for all-optical signal processing. Low temperature grown, proton bombarded or strain relaxed saturable absorber layers on Bragg mirrors have been characterized extensively for mode-locking purposes /1-2/. We present in this paper an investigation of the absorption bleaching and recovery dynamics of a reverse biased waveguide p-i-n saturable absorber. This device type has shown great applicability for high speed all-optical signal processing. Wavelength conversion and regeneration up to 40 Gbit/s and demultiplexing from 80 Gbit/s to 10 Gbit/s have been demonstrated recently /3-4/. However, only little data exist on the fundamental absorption properties of reverse biased waveguides and the dependence on operation parameters important for device optimisation.

Absorption saturation

The saturable absorber has a five quantum well InGaAsP layer embedded in a 250-μm long waveguide p-i-n structure. Short optical pulses from a commercial Coherent OPA laser system are used to measure the absorption saturation as function of temporal pulse width and reverse bias applied to the SA. The wavelength is 1520 nm, close to the absorption edge of the unbiased component. A pulse shaper following the laser source enables control of the temporal pulse width.

Figure 1 (a), shows the component transmission as function of the reverse bias and the input pulse energy for a 1-ps pulse. The coupling loss is estimated to ~6-dB per facet. The component is not anti-reflection coated. The active material loss at 0 V is measured to be 2.5-dB. The component transmission can be separated into three regimes as function of the pulse energy. For low pulse energy (<0.1 pJ) the component transmission is independent on the pulse energy. For an increasing reverse bias the absorption increases, as expected from the quantum-confined Stark effect. For pulse energies between 0.1 pJ and 10 pJ the component transmission increases with pulse energy. In this regime, the leading edge of the pulse saturates the absorption and therefore reduces the overall absorption of the pulse. With no external field applied (0 V) a negligible absorption bleaching is observed due to the low active material absorption. The maximum absorption saturation attainable increases with increasing reverse bias and becomes ~18 dB for a reverse bias of 10 V. Above ~10 pJ of pulse energy a clear signature of two-photon absorption (TPA) is observed, appearing as an increased absorption with pulse energy /5/. Figure 1 (b) shows the absorption measurements for a 200-fs pulse. The absorption curves are similar to the 1-ps pulse measurement for low pulse energies, but shows a strongly reduced absorption bleaching due to the more significant TPA for shorter pulses. At 10 V of reverse bias, the TPA limits the maximum absorption bleaching to ~10 dB.

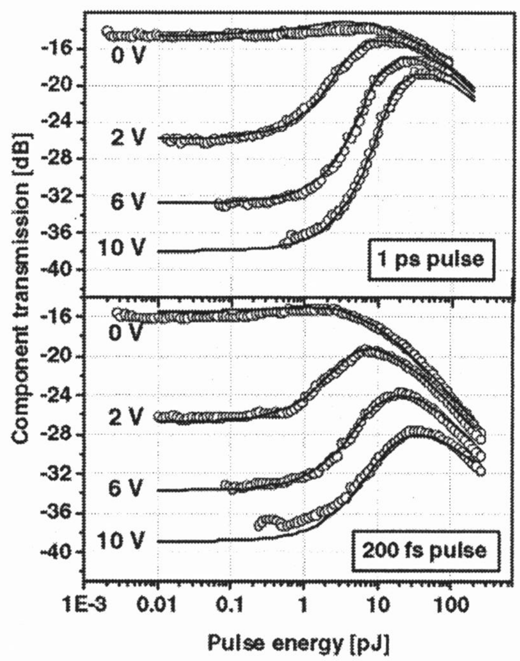

Figure 1 *Transmission through a 250-μm waveguide SA as function of reverse bias and pulse energy, (a) for a 1 ps pulse, (b) for a 200 fs pulse. Simulations of the transmission are also shown (full lines).*

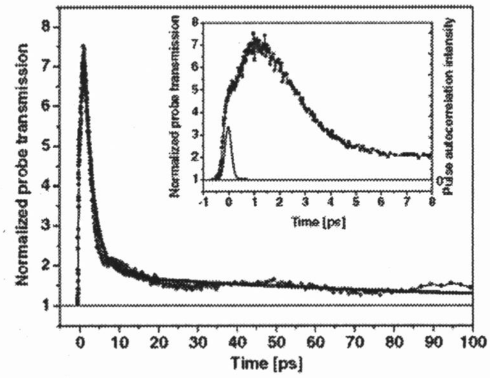

***Figure 2** Time-resolved pump-probe measurements of the absorption dynamics for 10 V reverse bias applied to the SA. The pump pulse energy is 3 pJ. Inset shows the response on a 10 ps time-scale and the pump and probe autocorrelation shape.*

Figure 1 also shows calculated absorption curves (full lines) The model is a standard rate-equation model with a phenomenological description of the carrier sweep-out, absorption saturation and TPA /6/. The saturation energies obtained from the different puls widths are identical (ranging from 150 fJ at 0 V to 400 fJ at 10 V) and it is concluded that the difference in absorption for the 200 fs and 1 ps pulse is solely due to TPA.

Absorption recovery

A heterodyne pump-probe technique was used to measure the absorption recovery as function of reverse bias applied to the SA. Figure 2 shows the normalized probe transmission as function of the delay between the 200-fs pump and probe. On a short time-scale (inset of Figure 2) a delay in the absorption bleaching is observed, explained by a combination of carrier thermalization and field screening. The pump pulse energy is 3 pJ and the SA is reverse biased by 10 V. The recovery of the absorption is well described by a double-exponential decay, with a fast initial recovery followed by a slower recovery. Figure 3 (a) shows the recovery time of the fast and slow component as function of reverse bias. A decrease of two orders of magnitude is observed for the fast component, when increasing the reverse bias from 1 V to 10 V, while the slow long time constant decreases only by a factor of two. Figure 3 (b) shows the amplitude of the fast and slow component in the double exponential fit, demonstrating that the fast component is dominant for reverse biases above 2 V. For all-optical demultiplexing the fast component determines the minimum width of the switching window, while the long component is likely to limit the base-rate.

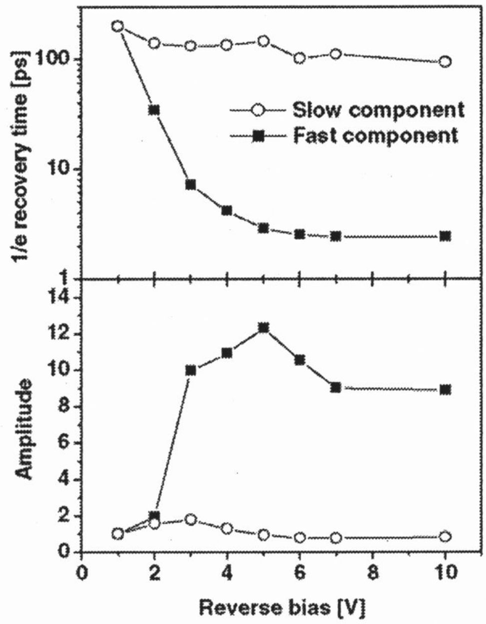

***Figure 3** (a) Recovery time for the fast and slow decay components in the double exponential fit of the absorption recovery. (b) Amplitude of the fast and slow decay components in the double exponential fit. The pump pulse energy is 3 pJ.*

However, 80-Gbit/s to 10-Gbit/s all-optical demultiplexing has been demonstrated using a similar component /4/. The long recovery tail is therefore not problematic for a base-rate of 10-Gbit/s.

Discussion and conclusion

We have characterized the properties of waveguide saturable absorbers relevant to their use for all-optical signal processing. Optimum gating pulse widths are of the order of 1-2 ps, shorter pulses are limited in extinction ratio by TPA, and longer pulses experience absorption recovery during excitation, thereby increasing the required pulse energy. The absorption recovery implies a minimum switching window of the order of 2 ps.

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